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Innovative Housing Grants Program

# ENERGY PERFORMANCE OF THREE AIRTIGHT DRYWALL APPROACH HOUSES

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The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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## FOREWORD

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## TABLE OF CONTENTS


| | Page No. |
|---|---|
| List of Tables | i |
| List of Photos | ii |
| Executive Summary | iii |
| 1.0 Introduction | 1 |
| 2.0 Overview of the Houses | 2 |
| 3.0 The Monitoring Program | 7 |
| 3.1 Overview | 7 |
| 3.2 Continuous Measurements | 7 |
| 3.3 Regular Site Visits | 9 |
| 3.4 Manual Measurements | 9 |
| 3.5 Non-instrumented Monitoring | 10 |
| 3.6 Special Site Tests | 10 |
| 4.0 Data Analysis | 11 |
| 4.1 Space Heating Systems | 11 |
| 4.2 Water Heating Systems | 13 |
| 4.3 Ventilation Systems | 14 |
| 5.0 Performance Evaluation | 15 |
| 5.1 Space Heating Systems | 15 |
| 5.2 Water Heating Systems | 17 |
| 5.3 Ventilation Systems | 17 |
| 5.4 House Envelope | 19 |
| 5.5 Air Quality | 23 |
| 5.6 Maintenance Costs | 26 |
| 5.7 Monitoring System | 26 |
| 6.0 Conclusions and Recommendations | 28 |
| 6.1 Advanced Development | 29 |
| References | 30 |

**APPENDICES**

A. Monitoring Equipment

B. Location of Monitoring Sensors

C. Summaries of Data Gathered

## LIST OF TABLES


| | | Page No. |
|---|---|---|
| 1. | Description of the Houses and Occupants ..... | 2 |
| 2. | Space Heating Systems ..... | 12 |
| 3. | Water Heating Systems ..... | 14 |
| 4. | Effect of Seasonal Gas Furnace Efficiency on Heating Costs ..... | 16 |
| 5. | Cold Weather Heating System Performance ..... | 16 |
| 6. | House Envelope Performance ..... | 20 |
| 7. | Ventilation Systems and Air-Leakage Rates .... | 21 |
| 8. | Contaminant Levels ..... | 23 |
| C-1. | Summary of Data Gathered - Bearspaw ..... | C-1 |
| C-2. | Summary of Data Gathered - River Ridge ..... | C-2 |
| C-3. | Summary of Data Gathered - Fountain Lake ..... | C-3 |
| C-4. | Summary of Data Gathered - Lessard ..... | C-4 |
| C-5. | Summary of Data Gathered - Ridgewood New ..... | C-5 |
| C-6. | Summary of Data Gathered - Ridgewood Old ..... | C-6 |

## LIST OF PHOTOS


| | | | | Page No. |
|---|---|---|---|---|
| 1. | Bearspaw | ADA | house ..... | 4 |
| 2. | River Ridge | ADA | house ..... | 4 |
| 3. | Fountain Lake | ADA | house ..... | 5 |
| 4. | Lessard | control | house ..... | 5 |
| 5. | Ridgewood New | control | house ..... | 6 |
| 6. | Ridgewood Old | control | house ..... | 6 |

## EXECUTIVE SUMMARY

The objective of this study was to assess a new construction technique, the *Airtight Drywall Approach (ADA)*, as it was implemented in three test houses, and to compare the performance of these houses against three control houses typical of residential construction techniques in Alberta.

The study focussed on four aspects of house performance - integrity of the air barrier system, energy conservation, ventilation, and indoor air quality, and the development and demonstration of computer-based field monitoring techniques.

Data was gathered through continuous computer-based measurements, regular site visits, manual measurements, homeowner interviews, and special site tests to:

a) record the change in air-leakage characteristics over a one-year period,
b) measure the energy used in operating the house,
c) record the factors which significantly affected the energy used,
d) record the performance of the heating and ventilation systems, and
e) measure typical indoor air quality parameters.

House performance was analysed by compiling the recorded monitoring data into daily totals and averages, and then into partial months. Factors describing the performance of the house envelope and the heating and ventilation systems were calculated from the compiled data and assessed.

The results of the air-leakage tests indicated that the Airtight Drywall Approach is an effective method of reducing air infiltration in homes. Infiltration in the homes using ADA techniques ranged from 0.61 to 1.80 air changes per hour (ac/h) at 50 Pa, while air leakage in the conventional homes ranged from 2.23 to 2.59 ac/h at 50 Pa. The floor joist sealing technique used in the ADA houses was observed to deteriorate within a year of construction. It is no longer recommended.

The monitoring results showed a significant reduction in energy consumption in the homes with energy conservation features. The data shows that a house built to current Canada Mortgage and Housing standards for conventional housing will consume 1.3 to 1.5 times the energy of a house incorporating such energy conservation features as higher insulation, reduced air infiltration, and heat recovery ventilators. Fuel costs were significantly lower in the homes equipped with a medium-efficiency, induced draft furnace.

Measurements of air-borne contaminants indicated that the ADA test homes performed similar to other energy-efficient homes monitored across Canada and that pollutant levels were within accepted guidelines.

Better transfer of information between the builder and the homeowner is essential if the homeowner is to understand how to operate and maintain the heating and ventilation systems in their house. Present homeowner knowledge of these systems is not sufficient for them to maximize the benefits that this new technology can provide.

The computer-based data acquisition methods provided a detailed understanding of mechanical system performance, and the effect of occupants, other mechanical systems, and manufacturer's design on system cycling, comfort levels, and temperature and efficiency profiles. The significant cost reductions in computer technologies in the last five years made this method of collecting hourly data feasible.

Special site tests using blower doors to measurement house air-leakage characteristics and dosimeters to measure indoor air quality allowed for a comparison among the six houses and with current building standards. A detailed understanding of house performance in these areas is not provided by this data, however, and will not be possible on a wide-spread basis until reductions in the cost of suitable computer-based monitoring sensors are realized.

**KEYWORDS**

Air barrier, energy conservation, ventilation, indoor air quality, home heating, data acquisition, data analysis, monitoring.

## 1.0 INTRODUCTION

Building research organizations are continually striving to improve the quality of houses and to reduce housing costs. As a result, new construction techniques and systems have been developed. Validation of this new technology is important since most builders are reluctant to change existing practices. The purpose of this study was to assess one of these new techniques, the *Airtight Drywall Approach (ADA)*, and to develop and demonstrate new lower-cost monitoring techniques.

Air leakage is most commonly managed using a caulked polyethylene method. However, this air barrier system is easily damaged and, once covered with drywall, can neither be inspected nor repaired. Strict supervision, especially in tract housing projects, is essential to ensure that the polyethylene air barrier is installed properly and not damaged. In addition, concern is being expressed about the long-term durability of polyethylene.

The Airtight Drywall Approach has the potential of reducing the cost of constructing a durable, airtight envelope (Lstiburek and Lischkoff, 1984), and of reducing installation problems. The only evaluation on the ADA building system previous to this study was conducted by the Ontario Ministry of Energy and Canada Mortgage and Housing Corporation on 15 houses in Ontario.

Three test houses were built in 1984 to evaluate ADA techniques. This study compared the performance of these houses against three control houses typical of residential construction techniques in Alberta. Four aspects of house performance were evaluated - the integrity of the air barrier system, energy conservation, ventilation, and indoor air quality.

Computer-based data acquisition systems (CDAS) have seen significant price reductions in recent years. As a result new products have become available for smaller scale field monitoring projects. Data gathering methods were developed for this study based on these products, and on methods used by the National Research Council of Canada (Hamilton and Alward, 1984).

Data on the performance of each house was gathered by air leakage tests, a CDAS, and indoor air quality dosimeters. Data from the CDAS was collected over a 9 month period and compiled into averages and totals. Performance factors were then calculated from the compiled data and compared.

## 2.0 OVERVIEW OF THE HOUSES

Six houses were monitored in this study. Five of the houses were built between May and September in 1984, one house was built in the autumn of 1981. Three of the houses were constructed using prototype Airtight Drywall Approach techniques. The other three were designated as control houses, and represented existing residential construction techniques in Alberta. Table 1 describes each of the houses and the occupants. Details on the construction of the ADA houses can be found in the report by Lstiburek (1985) listed in the references.

**Table 1. Description of the Houses and Occupants**

| Location | Description of ADA Houses |
|---|---|
| **Bearspaw** | o new, 140 m2 bungalow,<br>o ADA construction, |
| (Photo 1) | o homeowners are active retired grandparents,<br>o non-smoking,<br>o induced-draft natural gas furnace,<br>o electric water heater,<br>o central ventilation unit with heat recovery,<br>o family room fireplace,<br>o unfinished basement. |
| **River Ridge** | o new, 205 m2 two-storey,<br>o ADA construction,<br>o homeowners are a young couple with 2 infants, |
| (Photo 2) | o induced-draft natural gas furnace,<br>o induced-draft natural gas water heater,<br>o central ventilation unit with heat recovery,<br>o family room fireplace,<br>o finished basement with fireplace and sauna. |
| **Fountain Lake** | o new, 178 m2 split-level,<br>o ADA construction,<br>o non-smoking, |
| (Photo 3) | o homeowners are a young couple with 2 children in elementary and pre-school,<br>o induced-draft water heater providing space heating through a fan coil in the furnace,<br>o electric furnace used for auxiliary heating,<br>o central exhaust-only ventilation fan,<br>o family room fireplace,<br>o unfinished basement. |

Table 1. Description of the Houses and Occupants (continued)

| Location | Description of Control Houses |
|---|---|
| Lessard<br><br>(Photo 4) | o new, 205 m2 two-storey,<br>o modified ADA construction,<br>o homeowners are a young 30's couple with no children,<br>o non-smoking,<br>o induced-draft natural gas furnace,<br>o induced-draft natural gas water heater, and auxiliary electric water heater,<br>o central exhaust-only ventilation unit,<br>o family room and master bedroom fireplaces,<br>o finished basement with rumpus room, bedroom, and sauna. |
| Ridgewood New<br><br>(Photo 5) | o new, 81 m2 bi-level,<br>o conventional construction,<br>o homeowners are a young couple with an infant and a child in Grade 1,<br>o smoking,<br>o natural gas furnace with spark ignition and flue damper,<br>o conventional natural gas water heater,<br>o no central ventilation system,<br>o provision for fireplace,<br>o partially finished basement. |
| Ridgewood Old<br><br>(Photo 6) | o two-year old, 112 m2 bungalow,<br>o conventional construction,<br>o occupied by a mid-thirties couple with no children,<br>o smoking,<br>o natural gas furnace with spark ignition and flue damper,<br>o conventional natural gas water heater,<br>o no central ventilation system,<br>o family room fireplace used sometimes,<br>o partially finished basement. |

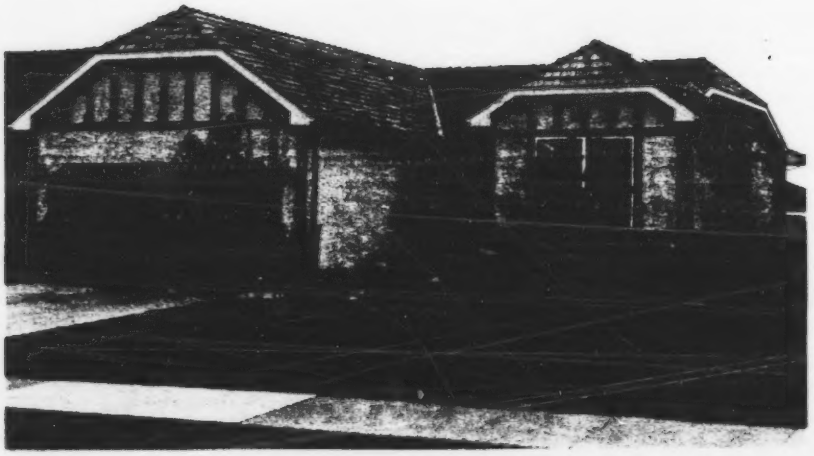

Photo 1. Bearspaw ADA house

Photo 2. River Ridge ADA house

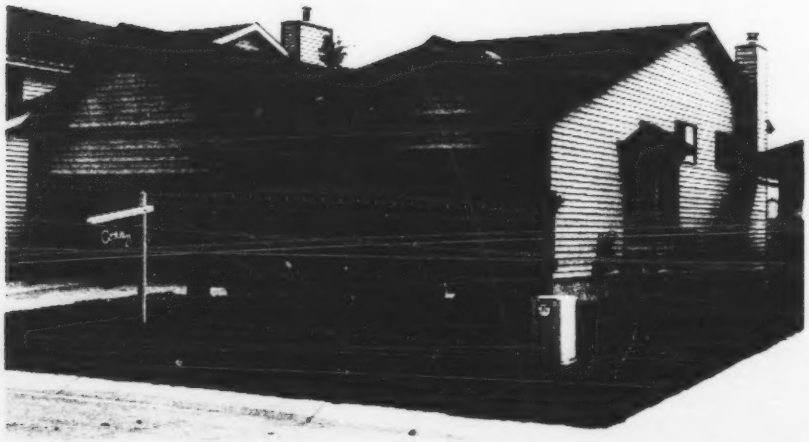

Photo 3. Fountain Lake ADA house

Photo 4. Lessard control house

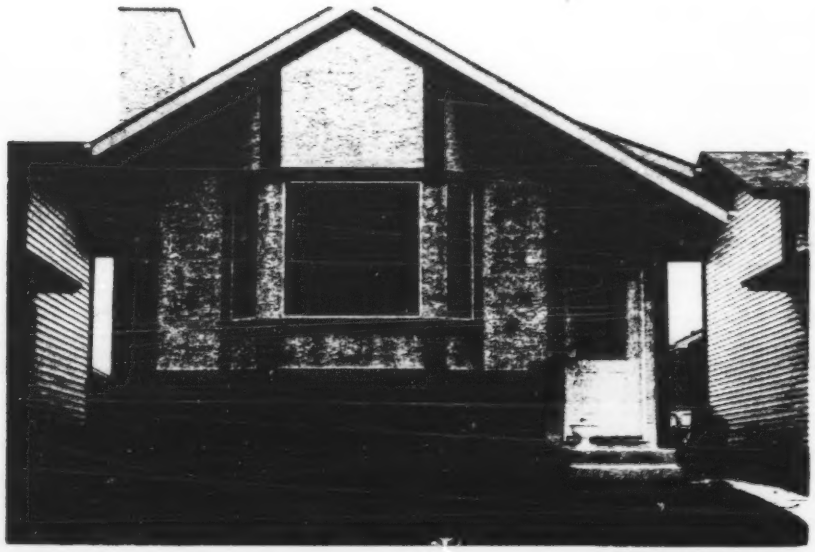

Photo 5. Ridgewood New control house

Photo 6. Ridgewood Old control house

## 3.0 THE MONITORING PROGRAM

### 3.1 OVERVIEW

The primary data gathering tasks in each house were to:

a) record the change in air-leakage characteristics over a one-year period,
b) measure the energy used in operating the house,
c) record the factors which significantly affected the energy used,
d) record the performance of the heating and ventilation systems, and
e) measure typical indoor air quality parameters.

Data was gathered using five methods:

a) continuous measurements of time-varying energy consumption patterns, weather, soil conditions, and occupant operating factors affecting it,

b) regular site visits to recover data disks, read utility billing meters, and ensure that the data acquisition system was operating correctly,

c) manual measurements of building, appliance and heating system constants for use in system performance equations,

d) non-instrumented monitoring to identify occupant activities and obtain homeowner feedback, and

e) special site tests to measure indoor air quality and building air-leakage.

These methods closely follow the procedures and guidelines in the Level B monitoring manual published by the Solar Energy Program of the National Research Council of Canada (NRCC) (Hamilton and Alward, 1984).

The Level B procedures were used as a basis for data gathering in order that the information from these houses would be compatible with the Level B house monitoring that the NRCC has conducted across Canada.

### 3.2 CONTINUOUS MEASUREMENTS

The energy consumption of each house and the factors affecting it were continuously measured by a computer-based data acquisition system (CDAS) over a 9 month period from

October 1985 to June 1986. The parameters monitored included the comfort conditions within the house, the outdoor environment, and the operation of systems and appliances for ventilation, space and water heating.

The CDAS consisted of an Apple II+ clone computer, a Sciemetrics Instruments 8082A data acquisition unit, and appropriate sensors including thermistors and LM 335 integrated circuits for temperatures, voltage and light detectors for mechanical system status, relative humidity sensors, water meters, electrical meters with pulse output circuits, and a pyranometer for solar energy. Monitoring system specifications are described in Appendix A. Appendix B lists the sensor locations.

Sensor measurements were taken at 30 to 60 second intervals. Temperature, solar radiation, relative humidity, and equipment operating-mode readings were accumulated into time-weighted averages and integrals using a trapezoidal method of integration. Pulses from the electricity meters and changes in equipment operating mode were counted. Once per hour, all accumulated values were stored on a floppy disk. The disk was retrieved during the site visit and the data compiled into daily and monthly totals and averages.

### 3.2.1 Outdoor Environment

Weather parameters such as horizontal solar radiation and dry-bulb air temperature were monitored in order that actual house performance could be compared with the performance calculated using long term weather data. In addition, soil temperature sensors provided data on the potential for freezing at footings.

### 3.2.2 Indoor Environment

Sensors measured indoor relative humidity, and temperatures in the main floor, basement, second floor, and individual rooms (Fountain Lake house only). These temperatures were used in energy performance calculations.

### 3.2.3 Ventilation System

The operation of the ventilation system affects both energy consumption and air quality. The Bearspaw and River Ridge houses have central ventilation systems with heat recovery, the Fountain Lake and Lessard houses have central ventilation systems without heat recovery, and the two Ridgewood houses have no central ventilation.

The heat recovery ventilators had air temperature sensors installed in the inlets and outlets of the fresh and exhaust air streams, and status sensors detecting the defrost mode.

### 3.2.4 Purchased Energy

a) Space heating. The consumption of natural gas used in space heating was determined by monitoring the on-time of the furnace main burner gas valve. The total energy consumed was determined by multiplying this time by the furnace gas consumption rate and the monthly gas energy density.

b) Water heating. The energy consumed for water heating was determined by multiplying the monitored on-time of the heating elements (on the electric heater) or the burner flame (on the natural gas heaters) by the gas or electricity consumption rate and the appropriate energy density.

c) Electricity. The electricity used for domestic purposes within the house contributes to the space heating. The electricity consumption was determined by counting pulses produced by the utility billing meter.

## 3.3 REGULAR SITE VISITS

The purpose of the site visits was to recover full disks of data and to check the operation of the computer, data acquisition system, and sensors. In addition, natural gas, electricity, and water utility meters were read to provide a backup to the monitored data. Interim visits were necessary to correct periodic monitoring problems.

## 3.4 MANUAL MEASUREMENTS

Values expected to remain constant over the monitoring period were measured for use in calculating performance factors. These values included the physical dimensions of the houses, the energy consumption rates for the furnaces and water heaters, and the air flow rates of the ventilation systems.

## 3.5 NON-INSTRUMENTED MONITORING

Homeowners were interviewed regarding life-style and energy use perceptions. Through the interview, the homeowners provided information on the thermal comfort of the house, the heating and ventilation system reliability, and their perceptions of energy usage and the new energy technologies.

## 3.6 SPECIAL SITE TESTS

Two fan depressurization tests were performed to measure air leakage rates, and determine whether any degradation had occurred in the gasketing material or caulking used in the ADA construction.

In addition, air quality sensors were placed in the houses to measure levels of nitrogen dioxide, formaldehyde, and radon daughter products.

## 4.0 DATA ANALYSIS

The purpose in analyzing the monitored data was to evaluate the behaviour of the house envelope and its heating and ventilation systems. The hourly recorded data from the monitoring system was compiled into daily values by totalling the system operating times and energy usage, integrating the solar radiation, and averaging the temperatures and relative humidity. Data which was in error due to monitoring system malfunction was not included. The valid daily data was then compiled into *partial* months. Tables of this data are included in Appendix C.

### 4.1 SPACE HEATING SYSTEMS

Factors describing the energy consumption of the space heating systems are summarized in Table 2. The energy costs are presented for an average Edmonton winter (5600 degree-days), and an annual cost based on the current Edmonton natural gas price of $2.68 per GJ (gigajoule). The data shows that fuel costs are significantly reduced in the homes equipped with a medium-efficiency, induced draft furnace.

The factors in Table 2 were determined as follows:

a) Developed floor area - as advertised by the builder.

b) Seasonal efficiency - as used by the HOT 2000 energy analysis software.

c) Cost of space heating excludes chimney losses and was calculated using the:
   - o monitored furnace operating time,
   - o measured furnace gas consumption rate,
   - o monthly gas energy density as provided by the gas utility company, and
   - o seasonal furnace efficiency.

   The Fountain Lake space heating system consisted of a natural gas water heater and an electric furnace backup. The energy consumption of this system was determined using the:
   - o monitored water heater operating time,
   - o measured water heater gas consumption rate,
   - o monthly gas energy density,
   - o seasonal water heater efficiency,
   - o energy measured in heating water for domestic purposes,
   - o operating time of the electric furnace elements, and
   - o electricity consumption rate of the electric furnace.

**Table 2. SPACE HEATING SYSTEMS**

| HOUSE | DEVELOPED FLOOR AREA (m2) | COST OF HEATING THE HOUSE ($/year) | FURNACE TYPE | SEASONAL EFFICIENCY (%) | CHIMNEY LOSSES ($/year) | TOTAL FUEL COSTS ($/year) |
|---|---|---|---|---|---|---|
| Bearspaw | 140 | 129 | Induced-draft | 79 | 34 | 163 |
| River Ridge | 205 | 173 | Induced-draft | 79 | 45 | 218 |
| Fountain Lake | 178 | 104 | Induced-draft water heater supplying a fan coil | 53 | 75 | 311 |
| | | 132 | Electric backup | 100 | 0 | |
| Lessard | 205 | 194 | Induced-draft | 79 | 49 | 243 |
| Ridgewood New | 81 | 138 | Spark ignition and flue damper | 69 | 62 | 200 |
| Ridgewood Old | 112 | 187 | Spark ignition and flue damper | 69 | 84 | 271 |

**Notes:** 1) The costs shown in this table are presented for an average Edmonton winter of 5600 degree-days, a natural gas price of $2.68 per GJ, and an electrical price of $11.94 per GJ (Fountain Lake heating system).

2) Costs do not include annual fixed charges of $99.60.

d) Chimney losses were calculated using the:
- o cost of space heating, and
- o seasonal efficiency of the furnace (or water heater in the Fountain Lake house).

e) Total fuel costs combine the cost of space heating and the chimney losses.
**Note:** This factor does not include the annual fixed charges amounting to an additional $99.60.

## 4.2 WATER HEATING SYSTEMS

Factors describing the energy consumption of the water heaters are summarized in Table 3. These factors were calculated from the measured daily energy consumption of the water heaters and are also presented as an annual cost. The costs shown in this table are presented for the current Edmonton natural gas price of $2.68 per GJ, and an electrical price of $11.94 per GJ (Bearspaw water heater).

The factors in Table 3 were calculated as follows:

a) Seasonal efficiency - as used by the HOT 2000 energy analysis software.

b) Cost of water heating excludes chimney losses and was calculated using the:
   - o monitored water heater operating time,
   - o measured water heater gas consumption rate,
   - o monthly gas energy density as provided by the gas utility company, and
   - o seasonal water heater efficiency.

   The energy used for electric water heating in Bearspaw was determined using the:
   - o monitored electric element operating time, and
   - o measured water heater electricity consumption rate.

The energy used for domestic water heating in the Fountain Lake house was calculated using the:
   - o average monitored cold water and domestic hot water temperatures,
   - o total monitored water volume, and
   - o seasonal water heater efficiency.

c) Chimney losses were calculated using the:
   - o cost of water heating, and
   - o seasonal water heater efficiency.

d) Total fuel costs combine the cost of water heating and the chimney losses.

**Table 3. WATER HEATING SYSTEMS**

| HOUSE | COST OF HEATING THE WATER ($/year) | TYPE OF WATER HEATER | SEASONAL EFFICIENCY (%) | CHIMNEY LOSSES ($/year) | TOTAL FUEL COSTS ($/year) |
|---|---|---|---|---|---|
| Bearspaw | 154 | Electric | 100 | 0 | 154 |
| River Ridge | 37 | Induced-draft | 58 | 27 | 65 |
| Fountain Lake | 37 | Induced-draft | 58 | 27 | 65 |
| Lessard | 27 | Induced-draft | 58 | 20 | 47 |
| Ridgewood New | 30 | Conventional | 45 | 37 | 67 |
| Ridgewood Old | 17 | Conventional | 45 | 21 | 37 |

**Note:** The costs shown in this table are presented for the current Edmonton natural gas price of $2.68 per GJ, and an electrical price of $11.94 per GJ.

## 4.3 VENTILATION SYSTEMS

Data on the ventilation systems was collected for the heat recovery ventilators (HRVs) at Bearspaw and River Ridge. An in-depth analysis of these HRVs cannot be made with confidence since air flows were not measured continuously. These air flows change as dirt gathers in filters and ice builds up in the heat transfer core.

Operation of the ventilator in the River Ridge house was examined for one day each of -30 C and 0 C weather. Commonly used performance factors - apparent effectiveness and sensible heat recovery efficiency - were calculated using equations from the CSA standard C439 (Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators).

## 5.0 PERFORMANCE EVALUATION

### 5.1 SPACE HEATING SYSTEMS

#### 5.1.1 Performance Factor Evaluation (Table 2)

a) Space heating costs give the amount of energy supplied to the house by the heating system to meet the difference between the envelope heat loss and the internal heat gains. This value is affected by the outdoor temperature, the amount of sunshine, and the amount of electricity consumed. It approaches zero during the warmer months when the internal gains are sufficient for house heating needs.

b) Chimney losses show the amount of energy lost up the chimney by the furnace. The value of chimney losses between different furnace types is illustrated in more detail in Table 4. The benefits of higher efficiency furnaces can clearly be seen in the houses with higher heat losses.

c) Total fuel costs indicate the annual cost of heating the house. As with "Space Heating Costs", it can vary widely from year to year, and is shown for an average Edmonton heating season.

**Table 4. Effect of Seasonal Gas Furnace Efficiency on Heating Costs**

| House | Space Heating Energy (GJ) | ---Type of Furnace--- (Efficiency) Conventional (60%) ($/year) | Upgraded (69%) ($/year) | Medium (79%) ($/year) | High (94%) ($/year) |
|---|---|---|---|---|---|
| Bearspaw | 48 | 215 | 187 | 163 | 137 |
| River Ridge | 65 | 287 | 250 | 218 | 183 |
| Fountain Lake | 50 | 222 | 193 | 169 | 142 |
| Lessard | 69 | 307 | 267 | 233 | 196 |
| Ridgewood New | 52 | 230 | 200 | 175 | 147 |
| Ridgewood Old | 70 | 312 | 271 | 237 | 199 |

Note: 1. The underscored values indicate the annual fuel costs for the currently installed heating system.
2. Upgraded refers to spark ignition and flue damper.

5.1.2 Cold Weather Operation

Data from two days of extremely cold weather on November 25 and 26, 1985 was used to assess heating system operation in greater detail. Outdoor temperatures reached -34 C, with an average indoor-outdoor temperature difference 50 C. Table 5 describes the operating performance of the space heating systems over these two days.

**Table 5. Cold Weather Heating System Performance**

| House | Furnace operating time (%) | Duration of burner cycle | Measured furnace input energy (kW) |
|---|---|---|---|
| Bearspaw | 43 | 1h 28m | 17.5 |
| River Ridge | 87 | 2h 59m | 16.4 |
| Fountain Lake | | | |
| o circulation pump | 100 | 24h | |
| o water heater | 64 | 11m | 10.2 |
| o electric furnace | 56 | 1h 7m | 10.0 |
| Lessard | 53 | 1h 9m | 24.1 |
| Ridgewood New | 45 | 23m | 25.1 |
| Ridgewood Old | 41 | 5m | 31.9 |

To attain maximum efficiency, a furnace should be sized to operate continuously at the winter design temperature. Data in Table 5 indicates that the furnaces are oversized in most of the houses. In low energy homes some oversizing is often necessary in order to obtain adequate air circulation and recovery from nighttime setback.

## 5.2 WATER HEATING SYSTEMS

Table 3 shows the amount of energy consumed in heating water. Savings resulting from the use of induced-draft water heaters were lower than expected as manufacturer's initial claims of efficiencies as high as 75% were never realized. Testing by the Ontario Research Foundation revealed efficiencies of only 58%. It is important also to note the increased cost of electric water heating in the Bearspaw house.

## 5.3 VENTILATION SYSTEMS

### 5.3.1 Exhaust-only Ventilators

The Lessard and Fountain Lake houses were equipped with exhaust-only central ventilation systems. Controls for the units were placed in locations difficult for the homeowner to access. In the Fountain Lake house, for example, the builder placed the speed control high between the basement ceiling joist spaces.

The Lessard homeowners operated the ventilator infrequently. The Fountain Lake homeowners did not operate the ventilation system at all.

### 5.3.2 Heat Recovery Ventilators

The Bearspaw and River Ridge houses were equipped with central heat recovery ventilator systems which have three modes of operation: low speed, high speed, and defrost. The low speed mode is designed to run continuously, the high speed mode is controlled by a humidistat, and the defrost mode operates intermittently in cold weather to control ice buildup in the ventilator core.

The intent of the humidistat is to keep the house humidity at a setting desired by the homeowner, with the intent that the homeowner would decrease humidity levels during colder weather to prevent condensation on windows. However, these devices were installed high in the basement ducting near the

ceiling, in a location where the homeowner required a stool to reach them. The homeowners did not appear to adjust the settings.

The HRV fans in both the houses became increasingly noisy during the first winter. The homeowner in Bearspaw turned the unit off at night. The noise did not bother the homeowner in River Ridge as much because the bedrooms were on the second floor, and the HRV was enclosed in a furnace room.

It appears that the HRVs are providing adequate ventilation for the houses, but it remains uncertain whether this ventilation is being provided in an optimum manner. Since the houses were constructed, improved models of the HRVs have become available.

### 5.3.3 Cold Weather Operation

HRV operation at the River Ridge house is shown below for two days in which outdoor air temperatures were similar to those under which HRVs are tested by the R-2000 program. Performance factors were calculated from the data gathered using a measured supply air flow rate of 46 l/s and exhaust rate of 57 l/s.

| | NO 26 | JA 10 |
|---|---|---|
| Outdoor hood temperatures | | |
| Supply air entering the house: | -30.2 C | -0.1 C |
| Exhaust air leaving the house: | 12.2 C | 10.3 C |
| HRV core temperatures | | |
| Supply air leaving the core: | 12.0 C | 19.7 C |
| Exhaust air entering the core: | 28.9 C | 25.4 C |
| Ambient temperatures | | |
| Basement: | 25.0 C | 19.6 C |
| Main floor: | 21.3 C | 22.4 C |
| Outdoor: | -31.4 C | -0.1 C |
| Operating Mode | | |
| Time in defrost mode: | 67 % | 0 % |
| Defrost cycling period: | 4.8 m | 0 m |
| Performance Factors | | |
| Apparent effectiveness: | 71 % | 78 % |
| Heat recovery efficiency: | 56 % | 53 % |

The apparent effectiveness of the HRV is the ratio of the actual heat transfer to the maximum possible. The heat recovery efficiency is a measure of how well the HRV transfers exhaust air heat to the supply air stream, and accounts for the energy required for fan operation.

The performance factors compare well with the laboratory testing of the HRV at an outdoor temperature of -25 C and a flow rate of 57 l/s, in which the effectiveness was measured to be 70% and the efficiency to be 58%.

### 5.3.4 Homeowner Interaction

Homeowner interviews revealed that homeowners did not have a clear understanding of the function of ventilation systems, nor how to clean filters, use speed controls, or set humidistats. This lack of knowledge affects the performance of the ventilators and their useful service life.

## 5.4 HOUSE ENVELOPE

### 5.4.1 Thermal Performance

Table 6 lists the contributions of the heating system and the internal gains to the total house envelope heat losses. The envelope losses were determined by adding the measured space heating energy, the measured gains from electricity and solar, and the estimated occupancy patterns. The internal gains listed consist of the heat generated by the electricity used for domestic purposes, the solar energy entering through windows, and the occupants.

From the envelope heat loss values in Table 6, the houses can be seen to fall into three groups which relate to the type of ventilation system, value of air-leakage, and the construction method.

The conventional houses were built to current Canada Mortgage and Housing standards - RSI 6 (R 34) in the ceiling, RSI 3.5 (R 20) in the main floor walls, and RSI 2.1 (R 12) in the basement walls. The data shows that these houses consumed 1.3 to 1.5 the energy of a house incorporating energy conservation features such as higher insulation, reduced air infiltration, and heat recovery ventilators.

**Table 6. House Envelope Performance**

| House Envelope | Envelope heat loss ($/year) | Contribution of Furnace (%) | Contribution of Internal gains (%) | Ventilation System | Air-Leakage Rate (ac/h)* | Type of construction |
|---|---|---|---|---|---|---|
| 1) Bearspaw | 221 | 58 | 42 | heat recovery | 0.52 | ADA |
| River Ridge | 228 | 58 | 42 | heat recovery | 0.82 | ADA |
| 2) Fountain Lake | 257 | 52 | 48 | exhaust only | 1.13 | ADA |
| Leesarc | 254 | 56 | 44 | exhaust only | 1.59 | modified ADA |
| 3) Ridgewood New | 332 | 55 | 45 | none | 2.86 | conventional |
| Ridgewood Old | 328 | 70 | 30 | none | 2.86 | conventional |

**Note:** The envelope heat loss is presented for: an average house of 140 m2 in developed floor area, an average Edmonton winter of 5600 degree-days, and the current price of natural gas ($2.68 per GJ).

ac/h = air changes per hour

### 5.4.2 Air-Leakage Rates

Two sets of fan depressurization tests were conducted on the six houses. The initial testing was carried out by a local air testing contractor using a Retrotec Door Fan between April and October 1984 upon the completion of each house. The second test was carried out in March 1986 by personnel from the University of Alberta using equipment designed by the Department of Mechanical Engineering. The results are shown in Table 7.

The air-leakage results from the second test were generally higher for the ADA homes suggesting a deterioration of the air barrier system. Smoke pencils were used to determine sources of air leakage. The following results describe the second test:

a) *Bearspaw*, (0.61 air changes per hour (ac/h))

This house was the tightest of the six homes tested. The flow rate at 50 Pa was approximately one half that of the next tightest house. Two leakage sites were noted prior to testing - the fireplace fresh air intake damper and a penetration from the house to garage where a central vacuum system had been installed. The vacuum exhaust was sealed prior to testing. No major leakage areas were detected.

b) *River Ridge*, (1.61 ac/h)

The basement of this home had been developed since the first test, and additional sources of air leakage included a bathroom fan, a fireplace and a television cable through the rim joist area. Air leakage was also noted through the rim joist caulking. It was no longer possible to repair this area, however, because of the basement development.

**Table 7. VENTILATION SYSTEMS and AIR LEAKAGE RATES**

| HOUSE | VOLUME (m3) | TYPE OF VENTILATION SYSTEM | AIR LEAKAGE RATE @ 50 PA Test 1 (ac/h) | Test 2 (ac/h) | CHANGE (%) |
|---|---|---|---|---|---|
| **R-2000 standards** | | | **1.50** | | |
| Bearspaw (ADA) | 653 | Heat Recovery | .52 | .61 | 17 |
| River Ridge (ADA) | 756 | Heat Recovery | .82 | 1.61 | 96 |
| Fountain Lake (ADA) | 610 | Exhaust Only | 1.13 | 1.80 | 59 |
| Lessard (modified ADA) | 756 | Exhaust Only | 1.59 | 1.69 | 6 |
| Ridgewood New (conventional) | 365 | None | 2.86 | 2.59 | -10 |
| Ridgewood Old (conventional) | 449 | None | 2.28 | 2.23 | -2 |

c) *Fountain Lake*, (1.80 ac/h)

Air leakage was detected at the rim joist area where the drywall had been fitted between the joists and then caulked to them. The caulking had deteriorated and the air barrier was no longer continuous. The basement had not been finished so these areas could be recaulked if desired. Envelope penetrations at appliance vents also showed significant leakage.

The floor joist sealing technique used in the ADA test houses is no longer recommended for use. Techniques outlined by Lstiburek ("Construction Experience Using the Airtight Drywall Approach", 1985) are expected to alleviate the problem of deterioration.

d) *Lessard*, (1.69 ac/h)

The two major sources of air leakage noted in this house were the lower track seal on the family room patio door and a gas line penetration into the basement. The basement area was completely developed preventing an inspection of the rim joist area.

e) *Ridgewood New*, (2.59 ac/h) *and*
*Ridgewood Old*, (2.23 ac/h)

The air change rates of these houses remained essentially the same as the first test.

### 5.4.3 Soil Temperatures

Several temperature sensors were placed at the footings of each house to determine whether or not the footings were in danger of freezing. Minimum monthly temperatures measured by these sensors are listed in Appendix C. Minimum footing temperatures for all houses, except Fountain Lake, occurred in February and March when temperatures were recorded between 5 and 6 C. At Fountain Lake, minimum footing temperatures of 3 and 4 C were recorded between December and March. For the winter of 1985-86, therefore, there was no concern for the footings freezing.

One area of the Fountain Lake house is supported by a grade beam on piles. Temperature sensors were placed at the base of the piling and under the grade beam. As expected, freezing occurred at the grade beam but the soil at the pad of the supporting pile remained unfrozen.

## 5.5 AIR QUALITY

Indoor air quality was tested using procedures similar to those which are used by the federal government's R-2000 Program. Three contaminants were monitored - nitrogen dioxide (NO2), formaldehyde (HCHO), and radon daughters. Levels of NO2 and HCHO were measured in March 1985, and HCHO and radon daughters were measured in March 1986. Each of the three types of contaminant detectors were exposed to the house environment for approximately seven days.

Results of the contaminant measurements are given in Table 8.

### 5.5.1 Nitrogen dioxide, (NO2)

Nitrogen dioxide is a product of combustion and can be introduced into the indoor environment by improperly vented fuel-burning appliances such as gas ranges, fireplaces, and kerosene space heaters, and by tobacco smoking.

**Table 8. CONTAMINANT LEVELS**

| HOUSE | VOLUME (m³) | TYPE OF VENTILATION SYSTEM | Nitrogen dioxide 1985 See Note 1) (ppm)* | Formaldehyde -------1985------ Living (ppm)* | Bedroom (ppm)* | -------1986------ Living (ppm)* | Bedroom (ppm)* | Radon daughters 1986 Basement (WL **) |
|---|---|---|---|---|---|---|---|---|
| **Health and Welfare Canada guidelines** | | | **.050** | **.100** | | | | **.200** |
| Bearspaw (ADA) | 653 | Heat Recovery | .001 | .049 | .049 | .084 | .058 | .007 |
| River Ridge (ADA) | 756 | Heat Recovery | .031 | .039 | .029 | .069 | .039 | .003 |
| Fountain Lake (ADA) | 610 | Exhaust Only | .039 | .061 | .056 | .051 | .095 | na |
| Lessard (modified ADA) | 756 | Exhaust Only | .019 | .140 | .110 | .065 | .005 | .003 |
| Ridgewood New (conventional) | 365 | None | .010 | .106 | .102 | .041 | .057 | .002 |
| Ridgewood Old (conventional) | 449 | None | .003 | .041 | .049 | .065 | .053 | na |

**Note:** 1) NO2 was placed in the furnace room or the family room. See text for further details.

* ppm = parts per million

** WL = working levels

Short term health effects of exposure to NO2 include irritation of the mucous membranes of the respiratory tract, changes in sensory perception at levels as low as 0.100 ppm (parts per million), and aggravation of respiratory illnesses at concentrations of 13 ppm or more.

Dosimeters, consisting of sealable vials containing an absorbing surface, were obtained from the Ontario Research Foundation (ORF) for determining concentrations of NO2. A dosimeter was placed in the furnace room of homes where the occupants did not smoke. In homes with smokers, a dosimeter was placed in the family room where higher concentrations of NO2 would be expected.

Levels of NO2 in all of the houses tested were below current Health and Welfare Canada guidelines of 0.050 ppm.

### 5.5.2 Formaldehyde, (HCHO)

Formaldehyde is commonly used in the manufacture of urea formaldehyde resins which are used as adhesives in particleboard, plywood, carpet backing, and furnishings. These materials release the formaldehyde gas into the air at a variable rate, depending on their age, surrounding humidity levels, and temperature.

Eye, nose, and throat irritation, coughing and asthma-like symptoms, headaches, dizziness, nausea, vomiting, and nose bleeds have all been reported by people living in houses with elevated formaldehyde levels. Most health effects related to formaldehyde exposure are temporary and disappear when the pollutant is eliminated. Repeated long-term exposure may increase a person's sensitivity to the gas, and to allergens such as dust.

Dosimeters similar to the NO2 vials were obtained from the Ontario Research Foundation (ORF) for determining concentrations of HCHO. The dosimeters were placed in the master bedroom and family room of each house.

Levels of HCHO in all of the houses tested, with the exception of the 1985 levels in the Lessard and Ridgewood New houses, were below current Health and Welfare Canada guidelines of 0.100 ppm. Although no pattern was evident from the results, a number of observations were made:

a) *Bearspaw*

Formaldehyde levels increased significantly from 1985 to 1986 (0.001 to 0.049 ppm). During that same period, the fan motors of the heat recovery ventilator (HRV) became increasingly noisy. As a result, the homeowners were turning the unit off at night. The low natural air leakage rate of this house combined with reduced ventilation could explain the increase in HCHO levels.

b) *Fountain Lake*

Formaldehyde levels measured in the bedroom in 1986 (0.095 ppm) were just below the limit (0.100 ppm) suggesting the need for greater ventilation in this area. The homeowner was not using the ventilator because the controls were located out of reach in the basement joist space making operation of the unit very inconvenient.

c) *Lessard*

This home had a lot of new furnishings which could account for the high HCHO levels monitored in 1985 (0.140 ppm). The levels measured in 1986 were below the current guidelines of 0.100 ppm.

d) *Ridgewood New*

High initial levels (0.106 ppm) could be the result of the furnishings and building materials associated with a new home. Levels were significantly lower in 1986.

5.5.3 Radon daughters

Radon gas enters the house primarily through cracks in the basement walls and floor, penetrations such as water pipes, electrical power conduits and floor drains, and sometimes via the water supply itself, if a well exists in radium-bearing rock.

Radon gas decays into radon "daughter" particles which themselves decay rapidly and emit radioactivity. These daughter products attach themselves to particles in the air, such as dust and smoke, and are eventually inhaled into the lungs where they lodge themselves and irritate the tissue. Radioactive radon daughters are measured by levels of concentration which indicate the risk of lung cancer.

Surveymeters obtained from R.A.D. Service and Instruments Ltd. in Scarborough, Ontario were used to detect concentrations of radon daughter products. The surveymeters consisted of a small pump which drew house air through a detecting device. They were placed in the basements of four of the homes.

Levels of radon in all of the houses tested were significantly below current Health and Welfare Canada guidelines of 0.200 WL (working levels).

## 5.6 MAINTENANCE COSTS

A significant reduction in energy consumption in the homes with energy conservation features is seen in the monitoring results. These results should be placed in perspective, however, since the cost of maintaining higher efficiency heating and ventilation technology can reduce the energy savings (Mayhew and Howell, 1986).

For example, the following mechanical system maintenance was recorded during the study:

- o replace noisy ventilator fans ($150),
- o replace the stainless steel flue of an induced-draft water heater ($250),
- o relight the pilot light on an induced-draft water heater several times ($40 per service call),
- o replace a night setback thermostat ($120).

## 5.7 MONITORING SYSTEM

### 5.7.1 Computer Operation

All of the monitoring computers experienced reliability problems due to intermittent hanging (ceasing operation), with a significant loss of data at the River Ridge and Lessard houses. The causes were never clear although they were suspected to arise from a sensitivity of the computers to changes in the household electrical power.

Several attempts were made to correct the situation, including the installation of metal oxide varistors on the power line to reduce power surges, all without a noticeable effect. A cost-effective solution to this problem would have been the installation of watch-dog timers to turn the computers off and on when they hung, but none were commercially available. An interim and somewhat primitive solution was found by using a 24-hour timer which turned the computer off and on once per day. As a result of the problems with these computers, Howell Mayhew Engineering is currently developing a watch-dog timer to ensure the reliability of unattended computer-based monitoring systems.

### 5.7.2 Data Acquisition Unit

The data acquisition units used in the study boasted a very high capacity to price ratio. The units worked very well, although one unit initially had a malfunctioning integrated circuit. It was replaced by the manufacturer without delay. This model is no longer in production, however, the manufacturer, Sciemetric Instruments in Ottawa, has an expanded product line with similar technology and price performance.

### 5.7.3 Software

Task-oriented data acquisition software was written for the controlling computer. Different tasks for each house were defined which directed the computer to measure the sensors and process the data into hourly stored values. Additional software was also written to compile the hourly stored data into daily and monthly values.

Data was acquired with this monitoring system at a rate of one channel in 2 seconds. This slow speed was due to the 1 MHz computer clock frequency (compared to speeds of 5, 8 and 12 MHz in present-day computers) and the use of AppleSoft BASIC which is an interpreted software language.

The monitoring software worked well considering the speed and memory limitations. As a result of this study, Howell Mayhew Engineering, Inc. is refining its data acquisition software using Turbo Pascal on IBM computers and integrating data analysis into it.

### 5.7.4 Sensors

The sensors generally performed well. The phototransistor and the voltage status sensors were a simple and cost-effective way to monitor the status of the mechanical systems. An initial problem in using the LM 335 temperature sensors and a design flaw in the electrical meter pulse output circuits were discovered and had to be overcome.

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

a) The results of the air-leakage tests indicated that the Airtight Drywall Approach is an effective method of reducing air infiltration in homes. Infiltration in the homes using ADA techniques ranged from 0.61 to 1.80 air changes per hour (ac/h) at 50 Pa, while air leakage in the conventional homes ranged from 2.23 to 2.59 ac/h at 50 Pa.

b) A house built to current Canada Mortgage and Housing standards for conventional housing will consume 1.3 to 1.5 times the energy of a house incorporating such energy conservation features as higher insulation, reduced air infiltration, and heat recovery ventilators. The cost of that energy can be significantly lower if the homes is equipped with a medium-efficiency, induced draft furnace.

c) Measurements of air-borne contaminants indicated that the reduction of air infiltration using ADA techniques did not decrease the quality of the indoor air. The air quality is similar to other energy-efficient houses and falls within acceptable levels established by Health and Welfare Canada.

d) The floor joist sealing technique used in the ADA houses was observed to deteriorate within a year of construction and is no longer recommended. Alternate techniques are outlined in "Construction Experience Using the Airtight Drywall Approach" (Lstiburek, 1985).

e) The builder should ensure that the homeowner understands how to operate and maintain the heating and ventilation systems in their house. Homeowner knowledge of these systems is not sufficient to maximize the benefits that this new technology can provide.

f) The speed of the monitoring system was marginally adequate for this study. Future studies should use IBM-XT class or MacIntosh computers because of their superior speed and memory size. It is recommended that a watch-dog timer be used to ensure that the computer will be quickly reset in the event that it shuts down due to a power line disturbance.

## 6.1 ADVANCED DEVELOPMENT

Current interests in housing research and development in Canada are becoming more directed towards ventilation, air quality, and mechanical system operation, particularly as the house is viewed as a system of interrelated parts.

a) There needs to be a longer term assessment of the air barrier integrity in ADA homes arising from the observed deterioration to confirm the durability of the components used for air sealing.

b) Further research is required in characterizing the combined interaction of heating and ventilation systems.

c) Additional research is also needed to characterize the effect of low outdoor air temperatures, high winds, or occupant activities such as opening windows and doors, smoking, cooking, and large gatherings on air infiltration, ventilation and the air quality. Actual daily air change rates and air contaminant levels are not well understood in an occupied house.

d) Product development is needed to simplify residential mechanical system technology in order that as little homeowner interaction as possible is required. Homeowners cannot be depended upon to optimize equipment efficiency.

e) Current advances in micro-electronics and sensors are creating new and cost-effective means by which house and system performance can be evaluated. Less expensive sensors and methods for the measurement of real-time air infiltration, indoor air quality, and envelope pressure differentials are needed.

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## APPENDICES

A. Monitoring Equipment

B. Location of Monitoring Sensors

C. Summaries of Data Gathered

## APPENDIX A. MONITORING EQUIPMENT

The monitoring equipment installed in the houses consisted of sensors, a controlling computer and a data acquisition unit.

### A. SENSORS

The following sensors were installed to measure the required parameters:

| Measured Parameter | Sensor used |
|---|---|
| Indoor air temperature | LM 335 integrated circuit. |
| Outdoor air temperature | LM 235 integrated circuit in a radiation shield. |
| Water temperature | YSI 44008 thermistor. |
| Soil temperature | LM 335 integrated circuit. |
| Equipment status | voltage detector. |
| Water flow | Neptune meter with a 1 litre pulse transmitter. |
| Electricity consumption | Sangamo kWh meter with a 25 kJ pulse transmitter. |
| Solar radiation | Kipp & Zonen CM-5 pyranometer in an aspirated housing. |
| Relative humidity | Omega Engineering RH-10 meter. |
| Burner flame status | phototransistor. |
| Air quality | AQRI dosimeter. |

### B. COMPUTER CONTROLLER

The computer used to control the data acquisition system, and to compile the measurements into hourly totals and averages was an Apple II+ clone, with 64 kB of RAM, one 140 kB floppy drive, a clock frequency of 1 MHz, and a clock-calendar card. A portable monitor was brought to the site to inspect the operation of the data acquisition system, the sensors, and the house during the visits.

## C. DATA ACQUISITION UNIT

The data acquisition unit used was a Sciemetric Instruments 8082A Electronic Measurement System manufactured in Nepean, Ontario. Its specifications include 64 channels of differential analog input capacity resolved to 12 bits, and 16 channels of digital inputs. A Sciemetric Instruments memory-mapped interface card was used to communicate with the Apple.

## D. SOFTWARE FOR DATA ACQUISITION AND ANALYSIS

Software for the monitoring system was written in AppleSoft BASIC based on previous experience with residential monitoring and data acquisition systems (Rekken and Howell, 1983) and on general data acquisition software supplied by Sciemetric Instruments. Additional Apple software was written for compiling the raw data into daily and monthly totals and averages.

## APPENDIX B. LOCATION OF MONITORING SENSORS

| House Code | Location | Type | Number of Sensors |
|---|---|---|---|
| BP | Bearspaw | bungalow | 21 |
| RR | River Ridge | two-storey | 19 |
| FL | Fountain Lake | split level | 28 |
| LS | Lessard | two-storey | 15 |
| RN | Ridgewood New | bilevel | 13 |
| RO | Ridgewood Old | bungalow | 12 |

| | | House codes |
|---|---|---|
| **Air temperatures:** | | |
| outdoor, | in shade of house ... | BP RR FL LS RN RO |
| main floor, | in return air duct .. | BP RR FL LS RN RO |
| upper floor, | in return air duct .. | RR LS |
| living room, | on wall ..... | FL |
| second bedroom, | on wall ..... | FL |
| lower bedroom, | on wall ..... | FL |
| family room, | on wall ..... | FL |
| basement, | on wall ..... | BP RR FL LS RN RO |
| **Soil temperatures:** | | |
| near footing: | | |
| | next to wall 200 mm above .... | BP RR FL LS RN |
| | at outside edge ..... | BP RR FL LS |
| | underneath ..... | BP RR FL LS RN |
| | under slab 400 mm in ..... | BP RR FL LS RN |
| | 1 m below ..... | RR FL LS RN |
| slab on grade: | | |
| | at footing ..... | FL |
| | at pile ..... | FL |
| in yard, 3 m from house: | | |
| | 50 mm below grade ..... | BP |
| | 3000 mm below grade ..... | BP |
| 300 mm outside of basement wall: | | |
| | 300 mm below grade ..... | RO |
| | 1500 mm below grade ..... | RO |
| | 2000 mm below grade ..... | RO |
| under slab 500 mm in from footing ... | | RO |
| basement centre floor ..... | | RO |
| **Air quality:** | | |
| nitrogen dioxide dosimeter ..... | | BP RR FL LS RN RO |
| formaldehyde dosimeter: | | |
| | master bedroom ..... | BP RR FL LS RN RO |
| | kitchen ..... | BP RR FL LS RN RO |

## APPENDIX B. LOCATION OF MONITORING SENSORS (continued)

| Heat recovery ventilation: | House codes |
|---|---|
| air stream temperature: | |
| warm stale exhaust ..... | BP RR |
| cooled stale exhaust ..... | BP RR |
| cold fresh supply ..... | BP RR |
| warmed fresh supply ..... | BP RR |
| fan status: | |
| defrost mode ..... | BP RR |
| **Furnace:** | |
| natural gas furnace status ..... | BP RR LS RN RO |
| air temperature: | |
| entering heating coil ..... | FL |
| leaving heating coil ..... | FL |
| fan status: | |
| low speed ..... | FL |
| high speed ..... | FL |
| electric heating elements status .... | FL |
| **Water heater:** | |
| natural gas water heater status ..... | RR FL LS RN RO |
| electric water heater status: | |
| top element ..... | BP LS |
| bottom element ..... | BP LS |
| water line temperature: | |
| cold supply to house ..... | FL |
| hot water for domestic use ... | FL |
| hot water for space heating .. | FL |
| heating coil return ..... | FL |
| water circulation pump status ..... | FL |
| volume of domestic hot water ..... | FL |
| **Miscellaneous:** | |
| electricity consumption ..... | BP RR FL LS RN RO |
| horizontal solar radiation ..... | BP |
| main floor relative humidity ..... | BP RR FL LS RN RO |

## APPENDIX C

## Summaries of Data Gathered

1. Bearspaw
2. River Ridge
3. Fountain Lake
4. Lessard
5. Ridgewood New
6. Ridgewood Old

Table C-1. SUMMARY OF DATA GATHERED - BEARSPAW

| | | 1985 | | | 1986 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Month | OC | NO | DE | JA | FE | MR | AL | MA | JN |
| Monitoring period | days | 13 | 29 | 29 | 30 | 27 | 7 | 19 | 20 | 27 |
| Air temperature - indoor | C | 18.0 | 19 | 17.6 | 18.3 | 17.6 | 17.5 | 17.8 | 18.8 | 19.7 |
| - outdoor | C | 2.6 | -13.8 | -5.7 | -6.3 | -12.4 | 2.7 | 3.5 | 12.0 | 15 |
| Measured degree-days | DD | 200 | 914 | 682 | 738 | 809 | 185 | 273 | 136 | 127 |
| Indoor relative humidity | % | | | | | 17 | 27 | 30 | 35 | 38 |
| Minimum soil temperature - at footing | C | 9 | 7 | 6 | 6 | 5 | 5 | 5 | 7 | 10 |
| Space heating energy | MJ | 1465 | 8228 | 6262 | 7017 | 7654 | 1024 | 1860 | 770 | 0 |
| Furnace - on-time | hours | 32 | 177 | 135 | 151 | 164 | 22 | 40 | 117 | 0 |
| - # times on | # | 30 | 115 | 119 | 100 | 104 | 18 | 33 | 16 | 0 |
| Water heating energy | MJ | 441 | 913 | 873 | 904 | 970 | 418 | 852 | 934 | 799 |
| Water heater - on-time | hours | 26 | 59 | 56 | 58 | 63 | 27 | 55 | 60 | 52 |
| - # times on | # | 118 | 258 | 260 | 265 | 259 | 85 | 193 | 201 | 171 |
| Gas energy density | MJ/ft3 | 1.00821 | 1.01349 | 1.01665 | .99767 | .99556 | .99134 | .98817 | .99028 | .99134 |
| Total electricity | MJ | 1291 | 2681 | 2725 | 2638 | 2667 | 970 | 1784 | 1997 | 1873 |
| Domestic electricity | MJ | 850 | 1968 | 1852 | 1734 | 1697 | 553 | 932 | 1063 | 1074 |
| Solar gain | MJ | 700 | 1641 | 1038 | 1171 | 1988 | 1125 | 1147 | 1548 | 1355 |

**Table C-2. SUMMARY OF DATA GATHERED - RIVER RIDGE**

| | | 1985 | | | 1986 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Month | OC | NO | DE | JA | FE | MR | AL | MA | JN |
| Monitoring period | days | 7 | 22 | | 24 | 12 | 28 | 27 | 20 | 28 |
| Air temperature - indoor | C | 20.6 | 22.2 | | 21.4 | 21.1 | 20.6 | 20.7 | 20.4 | 20.3 |
| - outdoor | C | 5.9 | -16.9 | | -5.2 | -10.4 | .5 | 3.4 | 11.2 | 15.1 |
| Measured degree-days | DD | 104 | 860 | | 638 | 378 | 564 | 466 | 183 | 146 |
| Indoor relative humidity | % | | | | | 15 | 21 | 22 | 30 | 36 |
| Minimum soil temperature - at footing | C | 10 | 7 | | 7 | 5 | 5 | 6 | 7 | 8 |
| Space heating energy | MJ | 1110 | 14131 | | 9245 | 4801 | 5417 | 2878 | 799 | 0 |
| Furnace - on-time | hours | 26 | 327 | | 217 | 112 | 158 | 98 | 29 | 0 |
| - # times on | # | 49 | 242 | | 291 | 123 | 1684 | 1579 | 510 | 0 |
| Water heating energy | MJ | 289 | 1140 | | 1136 | 528 | 1354 | 1256 | 696 | 0 |
| Water heater - on-time | hours | 16 | 63 | | 63 | 29 | 75 | 69 | 38 | 0 |
| - # times on | # | 47 | 164 | | 146 | 78 | 192 | 184 | 91 | 0 |
| Gas energy density | MJ/ft3 | 1.00821 | 1.01349 | 1.01665 | .99767 | .99556 | .99134 | .98817 | .99028 | .99134 |
| Domestic electricity | MJ | 636 | 3129 | | 2389 | 993 | 1423 | 668 | 194 | 0 |
| Solar gain | MJ | 591 | 2227 | | 1685 | 1498 | 3077 | 3129 | 2040 | 1649 |

Table C-3. SUMMARY OF DATA GATHERED - FOUNTAIN LAKE

| | | 1985 | | | 1986 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Month | OC | NO | DE | JA | FE | MR | AL | MA | JN |
| Monitoring period | days | 14 | 26 | 30 | 29 | 25 | 29 | 29 | 26 | 28 |
| Air temperature - indoor | C | 20.0 | 20 | 19.8 | 20.0 | 20.3 | 19.6 | 20.4 | 22.1 | 22.1 |
| - outdoor | C | 2.8 | -16 | -4.2 | -11.6 | -11.6 | .3 | 3.9 | 12.9 | 15.2 |
| Measured degree-days | DD | 241 | 937 | 771 | 748 | 799 | 553 | 479 | 240 | 192 |
| Indoor relative humidity | % | | | | | 19 | 26 | 25 | 29 | 34 |
| Minimum soil temperatures | | | | | | | | | | |
| - 200 mm above footing | C | 10 | 7 | 6 | 6 | 5 | 4 | 6 | 7 | 10 |
| - at footing | C | 10 | 8 | 3 | 3 | 4 | 4 | 6 | 6 | 9 |
| - family room piling | C | 10 | 7 | 6 | 6 | 5 | 4 | 6 | 7 | 10 |
| - family room footing | C | 6 | -4 | -5 | 0 | -4 | -1 | 1 | 5 | 11 |
| Space heating energy | MJ | 1952 | 11644 | 8663 | 8170 | 9623 | 4989 | 3380 | 1575 | 10 |
| - fan coil system | MJ | 1774 | 7244 | 7789 | 6899 | 6253 | 4377 | 3293 | 1326 | 2 |
| - auxiliary electric furnace | MJ | 178 | 4400 | 874 | 1271 | 3370 | 612 | 87 | 249 | 8 |
| - on-time | hours | 5 | 122 | 24 | 35 | 94 | 17 | 2 | 7 | 0 |
| - # times on | # | 11 | 160 | 36 | 55 | 115 | 32 | 4 | 6 | 2 |
| Domestic water heating energy | MJ | 456 | 911 | 860 | 1216 | 843 | 1098 | 1265 | 1192 | 1023 |
| Water heater - on-time | hours | 110 | 403 | 428 | 401 | 351 | 270 | 225 | 124 | 51 |
| - # times on | # | 835 | 2108 | 2223 | 2445 | 2217 | 1728 | 1298 | 663 | 186 |
| Gas energy density | MJ/ft3 | 1.00821 | 1.01349 | 1.01665 | .99767 | .99556 | .99134 | .98817 | .99028 | .99134 |
| Total electricity | MJ | 1738 | 8173 | 4811 | 4840 | 6229 | 3754 | 3064 | 9302 | 2011 |
| Domestic electricity | MJ | 1560 | 3773 | 3936 | 3569 | 2857 | 3142 | 2977 | 2886 | 2003 |
| Solar gain | MJ | 1108 | 2511 | 1913 | 1953 | 2919 | 2965 | 3021 | 2126 | 1355 |

Table C-4. SUMMARY OF DATA GATHERED - LESSARD

| | Month | 1985 OC | NO | DE | 1986 JA | FE | MR | AL | MA | JN |
|---|---|---|---|---|---|---|---|---|---|---|
| Monitoring period | days | 5 | 30 | 5 | 9 | 28 | 26 | 25 | 29 | 28 |
| Air temperature - indoor | C | 20.2 | 19.3 | 19.3 | 18.1 | 18.2 | 18.6 | 18.9 | 19.3 | 20 |
| - outdoor | C | -.5 | -13.5 | -13.3 | -6.9 | -13.1 | 1.3 | 2.6 | 12.5 | 14.9 |
| Measured degree-days | DD | 104 | 984 | 163 | 225 | 876 | 457 | 407 | 197 | 143 |
| Indoor relative humidity | % | | | | 17 | 15 | 21 | 21 | 30 | 35 |
| Minimum soil temperatures | | | | | | | | | | |
| - 200 mm above footing | C | 10 | 7 | | 5 | 3 | 3 | 5 | 7 | 10 |
| - at footing | C | 11 | 8 | | 8 | e | 6 | 7 | 8 | 9 |
| Space heating energy | MJ | 1014 | 14143 | 2519 | 3209 | 11752 | 5081 | 3694 | 1822 | 318 |
| Furnace - on-time | hours | 20 | 235 | 41 | 52 | 185 | 84 | 60 | 30 | 5 |
| - # times on | # | 211 | 1002 | 111 | 232 | 310 | 222 | 200 | 120 | 16 |
| Water heating energy | MJ | 244 | 752 | 126 | 255 | 738 | 792 | 764 | 755 | 763 |
| Water heater - on-time | hours | 13 | 39 | 7 | 13 | 38 | 41 | 40 | 39 | 40 |
| - # times on | # | 37 | 155 | 24 | 40 | 154 | 170 | 141 | 170 | 161 |
| Gas energy density | MJ/ft3 | 1.00821 | 1.01349 | 1.01665 | .99767 | .99556 | .99134 | .98817 | .99028 | .99134 |
| Domestic electricity | MJ | 366 | 1721 | 2869 | 7433 | 2271 | 2252 | 1809 | 2482 | 2308 |
| Solar gain | MJ | 468 | 3478 | 378 | 725 | 3929 | 3009 | 2968 | 2912 | 1578 |

Table C-5. SUMMARY OF DATA GATHERED - RIDGEWOOD NEW

| | Month | 1985 SE | OC | NO | DE | 1986 JA | FE | MR | AL | MA | JN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Monitoring period | days | 29 | 27 | 30 | 27 | 31 | 15 | 31 | 29 | 30 | 17 |
| Air temperature - indoor | C | 19.6 | 19.9 | 19.8 | 19.4 | 19.7 | 19.7 | 18.8 | 18.8 | 20.0 | 21.4 |
| - outdoor | C | 7.2 | 3.6 | -14 | -5.6 | -5.6 | -7.5 | .6 | 3.6 | 12.2 | 15.3 |
| Measured degree-days | DD | 358 | 441 | 999 | 656 | 781 | 408 | 564 | 442 | 233 | 184 |
| Indoor relative humidity | % | | | | | | 28 | 29 | 29 | 34 | 34 |
| Minimum soil temperatures | | | | | | | | | | | |
| - 200 mm above footing | C | 11 | 9 | 4 | 3 | 5 | 2 | 3 | 7 | 8 | 14 |
| - at footing | C | 12 | 11 | 7 | 7 | 7 | 6 | 6 | 8 | 9 | 12 |
| Space heating energy | MJ | 1969 | 3213 | 11188 | 7366 | 8211 | 4023 | 4988 | 3527 | 1323 | 0 |
| Furnace - on-time | hours | 33 | 54 | 188 | 124 | 139 | 68 | 83 | 60 | 13 | 0 |
| - # times on | # | 98 | 162 | 634 | 813 | 993 | 461 | 550 | 394 | 164 | 0 |
| Water heating energy | MJ | 747 | 776 | 923 | 884 | 1168 | 558 | 1128 | 804 | 751 | 504 |
| Water heater - on-time | hours | 29 | 52 | 62 | 59 | 78 | 37 | 76 | 63 | 50 | 34 |
| - # times on | # | 142 | 135 | 149 | 146 | 198 | 85 | 204 | 177 | 139 | 103 |
| Gas energy density | MJ/ft3 | 1.02298 | 1.00821 | 1.01349 | 1.01665 | .99767 | .99556 | .99134 | .98817 | .99028 | .99134 |
| Domestic electricity | MJ | 376 | 2158 | 4062 | 3036 | 3388 | 1836 | 2492 | 2196 | 2072 | 1387 |
| Solar gain | MJ | 1175 | 1127 | 1335 | 714 | 958 | 960 | 1850 | 1837 | 1607 | 445 |

Table C-6. SUMMARY OF DATA GATHERED - RIDGEWOOD OLD

| | Month | 1985 OC | NO | DE | 1986 JA | FE | MR | AL | MA | JN |
|---|---|---|---|---|---|---|---|---|---|---|
| Monitoring period | days | 3 | 30 | 29 | 30 | 25 | 30 | 30 | 21 | 28 |
| Air temperature - indoor | C | 19.4 | 19.2 | 18.6 | 18.1 | 18.1 | 18.6 | 18.9 | 19.6 | 18.3 |
| - outdoor | C | -1.1 | -14 | -5.5 | -5.7 | -13.3 | .0 | 3.3 | 8.6 | 14.6 |
| Measured degree-days | DD | 62 | 984 | 698 | 720 | 785 | 463 | 468 | 221 | 104 |
| Indoor relative humidity | % | | | | | 19 | 23 | 24 | 27 | 40 |
| Minimum soil temperatures | | | | | | | | | | |
| - 500 mm above footing | C | 10 | 7 | 5 | 5 | 4 | 4 | 6 | 8 | 12 |
| - at footing | C | 11 | 9 | 7 | 7 | 6 | 6 | 7 | 8 | 11 |
| Space heating energy | MJ | 767 | 13474 | 9320 | 9568 | 9862 | 6640 | 4637 | 2495 | 760 |
| Furnace - on-time | hours | 10 | 181 | 125 | 129 | 132 | 89 | 62 | 33 | 11 |
| - # times on | # | 95 | 2210 | 1623 | 1884 | 1129 | 877 | 840 | 396 | 379 |
| Water heating energy | MJ | 55 | 854 | 546 | 485 | 398 | 406 | 575 | 153 | 372 |
| Water heater - on-time | hours | 4 | 57 | 26 | 32 | 26 | 27 | 38 | 10 | 25 |
| - # times on | # | 12 | 148 | 89 | 88 | 74 | 84 | 85 | 52 | 136 |
| Gas energy density | MJ/ft3 | 1.00821 | 1.01349 | 1.01665 | .99767 | .99556 | .99134 | .98817 | .99028 | .99134 |
| Domestic electricity | MJ | 179 | 2731 | 1888 | 1765 | 1816 | 1736 | 1754 | 885 | 2114 |
| Solar gain | MJ | 84 | 711 | 422 | 561 | 992 | 1496 | 1709 | 1401 | 1572 |